

BUILDING CONSTRUCTIONS MADE OF PERFORATED METALLIC MATERIALS

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ABSTRACT

The formation of cellular building constructions made of perforated steel band is presented in the paper. The information about the main mechanical properties of perforated tapes and plates is provided. Basic technological methods for obtaining cellular structures from perforated metallic tape achieved from waste material by stamping are suggested. The main attention is focused on the analysis of the compressive strength of key elements of cellular structures. Examples of the use of cellular structures made of perforated metallic materials in building construction are given. Special attention is paid to the manufacturing of sandwich panels based on a honeycomb structure made of perforated metal tape.

Key words: metallic sheets and profiles, perforation, welding, sandwich panels

INTRODUCTION

Perforated metallic materials have a big potential to be used in construction. Stiffness, strength and elastic/plastic properties of perforated metallic materials open up good opportunities for their wide range of use in the building industry.

For example they could be used as spacers for wall and floor constructions, reinforcement materials, fixtures and connectors for nodes of wooden constructions, etc. (Ozola, 2011; Kaļva, 2011) Because of high strength, light weight, good painting abilities and easy installation, perforated materials are becoming widely used in the design of building facades.

The main aim of the investigation is to propose different cellular building structures and constructions made from perforated plates or tapes.

MATERIALS AND METHODS

The properties of perforated metallic materials as end products directly depend on the mechanical and technological properties, intended perforation types, shapes, sizes, steps and other characteristics of used material. The technology of perforation also affects mechanical properties of the perforated end product. In order to select the required perforation technology and related equipment we should know the mechanical properties of the used material - density, tensile strength, hardness, etc.

The main materials for producing perforated construction elements are the steel, aluminium and copper. Sheet materials from aluminium and copper could be used in construction due to their high

corrosion resistance and architectural impression, but steel – due to its relatively high strength. Besides, aluminium alloys are lightweight and have sufficiently high strength they have good machinability during perforating and durability. Copper is widely used for roof covering. The oxide layer provides high corrosion resistance and, consequently, durability. Copper sheets have good machinability during perforating as well as good weldability. Nevertheless, steel perforated materials have better perspectives for use as a material for cellular building structures and constructions due to their lower cost and higher strength.

The weight of perforated aluminium products will be lower, but at the same time, the final products from perforated aluminium will have worse tensile strength properties compared to other materials, referred to in Table 1. Harder workable materials due to their mechanical properties are steel and different copper alloys. However, the strength of constructions is much better.

Mechanical properties of different types of metallic materials (tapes, plates) change during punching (Fig. 1, Fig. 2). The relationships shown, characterise the yield strength ratio and effective elastic properties depending on the percentage of perforation (O'Donell & Associates, Inc. 1993). The above mentioned relationships achieved for a perforated plate with round holes in a standard staggered 60° pattern are shown in Fig. 3. It is evident that the perforation reduces the yield strength ratio and effective elastic properties. The modulus of elasticity and Poisson's ratio of metallic material shows ultra-rapid changes.

Table 1

Mechanical properties of metallic materials used in the production of perforated tapes and plates

Materials	$\rho, \frac{kg}{m^3}$	σ_t, MPa	HB (MPa)	Marks of material
Steel	7700 – 7900	320 – 930	1310 – 2550	C50E, C22E, C8E, S235JRG2
Aluminium alloys	2700	60 – 310	520 – 847	AMg2H2, AD31T1
Copper alloys	8920 – 8980	220 – 640	1186 – 2430	M1-M3

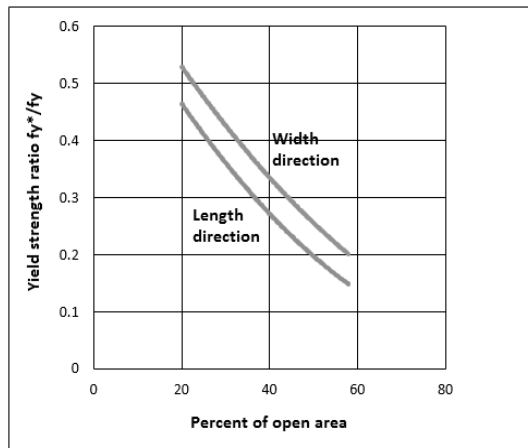


Figure 1. Yield strength ratio depending on percent of perforation, where f_y^* - yield strength of perforated plate; f_y - yield strength of unperforated plate

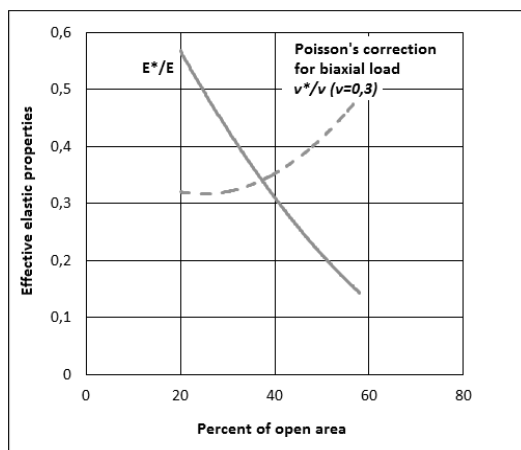


Figure 2. Effective elastic properties depending on the percentage of perforation, where E^* - elastic modulus of perforated plate; E - elastic modulus of unperforated plate; ν^* - Poisson's ratio of perforated plate; ν - Poisson's ratio of unperforated plate

Main methods for manufacturing of different types of cellular building constructions from perforated metallic materials are stretching, corrugation, plate shearing, cut-sheet and stretching, perforated tape twisting, method of interlacement, profiling and welding (Wadley et al., 2003; Mironovs et al., 2012,

Bogojavenskij et al., 1978). The right choice of method is directly affected by the properties of raw and perforated materials. For example, the method of stretching requires a slightly high strength of glued locations of connected plates

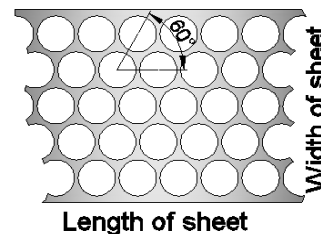


Figure 3. Perforated plate with round holes arranged in 60° angle

(enough to allow the stretching of the structure) which in the case of a thin cell wall is usually provided with modern adhesive polymers. The value of force necessary for stretching the cells steadily approaches the strength of adhesion between the plates, when the ratio of the cell wall's thickness against the cell size increases. In this case, for the production of a honeycomb structure with a higher relative density, another method of manufacturing (corrugation) or method of joining the elements (welding, soldering) is necessary. The usage of perforated metallic materials opens up new possibilities for the production of fundamentally new cellular materials and constructions. There are a variety of structure and mechanical properties that can be produced using different profiling and bonding methods. The usage of such structures in sandwich panel core raises particular interest.

EXPERIMENTAL STUDIES

Formation of cellular building constructions

In the experimental investigation we used samples from perforated steel tapes, obtained from waste in the production of driving chain (Lisicins et al., 2011; Mironovs et al., 2006; Products 2013). This structure was made from bands of LPM-1 – trade mark of JSC “Ditton Driving Chain Factory”, Latvia (Table 2).

Samples of cellular structures were made from perforated steel tape using profiling and welding. Profiling was made in crosswise direction (Fig. 4) and in longitudinal direction (Fig. 5). Previously profiled tapes were joined. As a result, cavities were generated between the tapes (Fig. 6, a and Fig. 6, b). Subsequently cavities may be filled, for example, by insulating filler.

It was experimentally determined that profiling of tape of C50E steel is hard to implement and possible only with high curvature. For example, there was cracking observed with a bend radius of less than 30 mm for several types of tape.

The profiling by bending in the case of C8E steel was much easier. This material is soft and ductile.

Table 2

Mechanical and geometrical characteristics of perforated steel band produced by punching

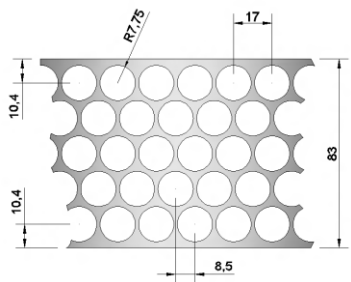
Type of band & geometrical characteristics	Designation	Material	Permeable area, %	Thickness, mm	Tensile strength, N/mm ²
	LPM - 1	Steel S235JRG2	66.97	1.50	320.70



Figure 4. The crosswise profiling

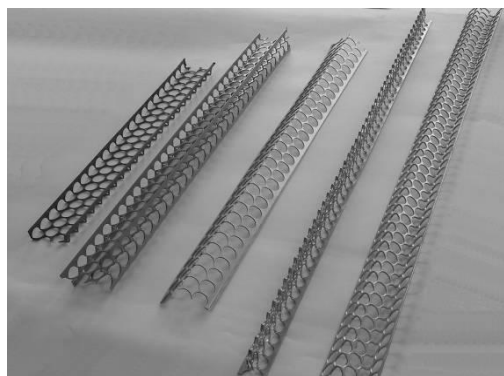


Figure 5. The longitudinal profiling

There were different profiles experimentally obtained by bending in the profiling machine – with a radial curvature of 90° and a greater angle

curvature. LPM – 1 sample of tape can be bent even slightly less than 180° due to its thin dimension. Previously profiled tapes were joined by resistance spot welding (RSW) using experimental AC RSW equipment „Impulse KM” earlier elaborated in Riga Technical University. The outer diameter of the spot weld is in the range of 4...5 mm (Mironovs et al., 2012). RSW welding parameters are given in Table 3.

Table 3

RSW welding parameters for steel S235JRG2 welding

Welding parameters	Welding current range, kA	Electrode force, kN	Weld time, sec (50 Hz cycles)
Conditions	8...9	3.5...4.0	0.18...0.20

Assessment of deformation of cellular structures

One of the aims of modeling cellular structures with complex shapes and structures of the material is the determination of their deformation properties. Computer modeling using FEM (Finite Element Method) was done using CAE module of design software SolidWorks – COSMOSWorks. Experimental tests performed on the compression setting Zwick Z100.

Evaluation of mechanical properties was carried out using an elaborated model of the basic element (Fig. 7.) of the structure shown in Fig. 8. The

collapse of cellular structure element occurred as a result of local carrying capacity loss (Fig. 9.).

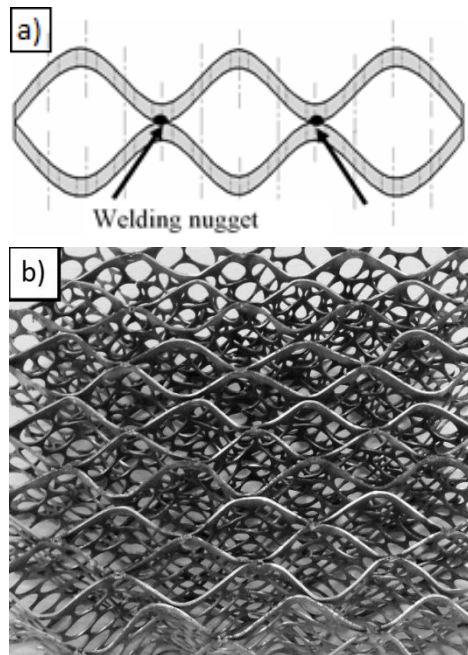


Figure 6. Scheme of assembly (a) and cellular structures from S235JRG2 perforated tapes (width 100 mm, thickness 1.2 mm) produced by RSW (b) The scheme of the welded cellular structure is given in Fig. 6 a, but the view of the cellular structure is shown in Fig. 6, b. Preliminary experiments were

revealed that resistance welding is an appropriate technology for the generation of cellular structures.

Results of tests are shown in Fig. 9 and Fig. 10. Compression force ranged from 2644 N to 2815 N. The maximum deformation by the y-axis is 1.0...1.4 mm. The average load capacity (2744 N) results in average deformation 1.17 mm.

The maximum deformation was 1.15 mm, which is at 1.17% lower than experimental results. The difference between results obtained by computer simulation and experimental work is in the range of 5%. Thus, computer simulation is a feasible way to predict the deformation of geometrically complex cellular structures, using perforated bands.

The compressive strength test results for the metallic core elements of the cell structure are shown in Table 4, where:

- H – height of cellular structure
- $A_{s,eff}$ – effective cross-sectional area
- $F_{c,max}$ – maximal load carrying capacity
- $\Delta l_{c,Fmax}$ – maximal deformation
- ϵ_{Fmax} – maximal strain
- σ_c – compressive stress

It is also worth noting that all the welds passed the above-mentioned load, and hence the strength of the pins provided no less strength than that of the construction. The local loss of load carrying capacity was observed in the walls between perforation.

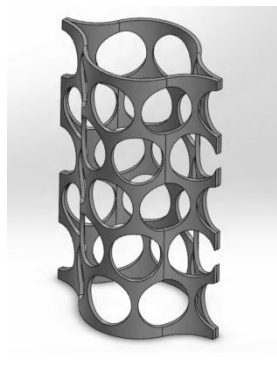


Figure 7. The model of basic the element of the cellular structure for FEM calculation

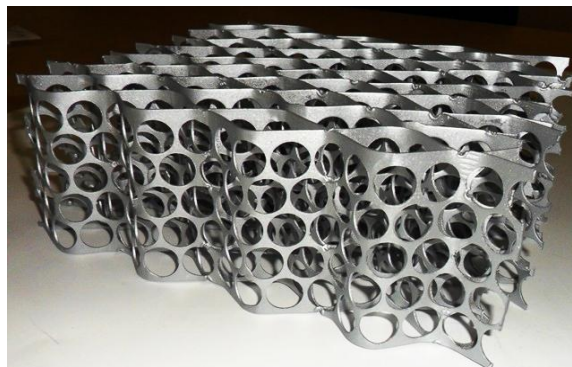


Figure 8. Cellular structure made of perforated bands

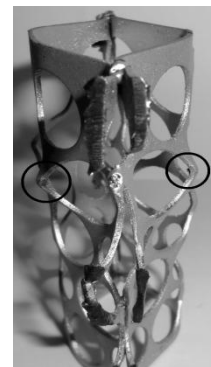


Figure 9. The tested element of cellular structure

Table 4

Compressive strength test results for the metallic core elements of the cell structure

No.	H, mm	$A_{s,eff}$	$F_{c,max}$, N	$\Delta l_{c,Fmax}$, mm	ϵ_{Fmax} %	σ_c , N/mm ²
1.	83	14.40	2773.20	1.0	1.20	192.58
2.	83	14.40	2643.93	1.5	1.81	183.61
3.	83	14.40	2814.98	1.0	1.20	195.48
Average results:		14.40	2744.04	1.17	1.40	190.56

CELLULAR METALLIC STRUCTURES IN BUILDING CONSTRUCTION

One of the usage possibilities of perforated metallic materials in building construction is sandwich panels.

Sandwich panel is a composite structure in which two stiff outer skins are bonded to a relatively thick but lightweight core. The panels are preferred in applications requiring a structure that is both highly resistant to bending and extremely lightweight. The facing skins of a sandwich panel can be compared to the flanges of an I-beam, as they carry the bending stresses to which the beam is subjected.

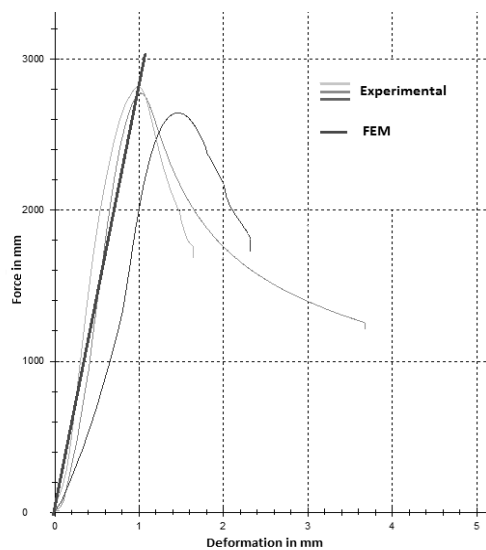


Figure 10. The curves of the deformation of the load

By splitting a solid laminate down the middle and separating the two halves with a core material, the result is a sandwich panel. The new panel weighs a little more than the laminate, but its flexural stiffness and strength are much greater (Table 5). By doubling the thickness of the core material, the difference is even more striking (Petras et al., 1998).

By use of perforated metallic tapes or plates the weight of the sandwich panel can be reduced even more. In that case, the load carrying capacity of the panels will be reduced. However, in most cases it is enough to provide functioning of the construction under load (especially in the case of facade panels). The use of perforated sheets also provides additional opportunities for the installation of fastenings of the panels depending on the constructive solution. There are the opportunities to join the elements of the core of the sandwich panel by wire, sleeves, nuts, etc. Using perforated steel waste materials, the compressive strength of the cell structure is sufficient (Table 4) to ensure safe work

One facing skin is in compression, the other - in tension. The core resists the shear loads, increases the stiffness of the structure by holding the facing skins apart, and improving on the I-beam, it gives continuous support to the flanges or facing skins to produce a uniformly stiffened panel. The core-to-skin adhesive rigidly joins the sandwich components and allows them to act as one unit with a high torsional and bending rigidity. The separation of the skins by the core increases the moment of inertia of the panel with little increase in weight – in such a way an efficient construction with good bending and buckling strength is obtained.

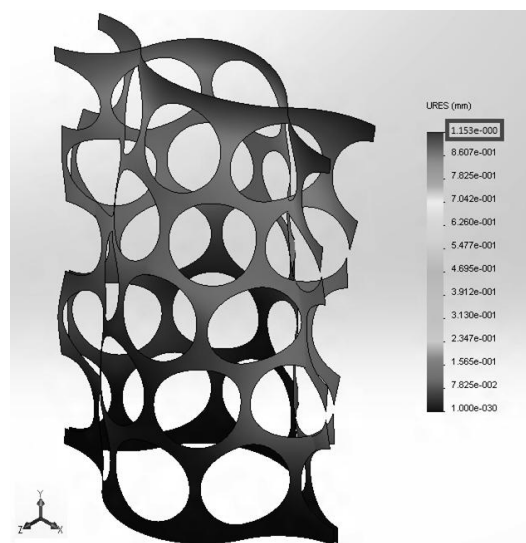


Figure 11. View of deformation

of panels even in floor constructions, but lower costs significantly increase the economic efficiency. Sandwich panels shown in Fig. 11 and Fig. 12 are diverse in terms of the types of profile and their distribution. Profiles can be based on the perforated tape with different widths and thicknesses. The percentage of open area (perforation) also may vary. The profiling of tape may vary depending on the engineering solution of the construction and expected load. Profiles of the core can be arranged upright (Fig. 11) or flatwise (Fig. 12) relative to the cladding. All these parameters are chosen according to the mechanical properties of the profiles (and their material) and expected service circumstances of the end product (panel). For example, profiles arranged upright have a greater load carrying capacity, but those placed flatwise – better connection options with cladding sheets, as well as mechanical energy absorption capability. Core sheets are commonly completed with profiling in the transversal direction. The method of stretching, corrugation or slotting (especially in the case of the

perforated metallic waste materials) can be efficiently used for production of the core. Cavities between the plates of the panel may be empty or filled by thermal or acoustic insulating materials. The upper cladding sheet of the panel can consist of only one layer, for example, in the case of interior facing panels, or multilayer, where the lower layer smoothly splits the load, but the upper layer is decorative and connected to the upper layer with a layer of glue or a damping layer is applied on top – in the case of floor panels. Artificial or natural stone materials – granite, marble, limestone, sandstone, etc, may create the upper decorative layer.

Panels based on a metallic cell structure can be used as load carrying or non-load carrying constructions. They can be used for wall, floor, stairs and door constructions, scaffolding and gantry constructions, pre-manufactured and pre-fabricated garages, car shelters, bus stops, shower and toilet modules. The main benefits of perforated metallic materials usage in sandwich panel's constructions:

- weight reduction (compared with non-perforated metallic materials);
- fire resistance;
- noise reduction or acoustic effects;
- ventilation possibilities;
- durability and vandal proof.

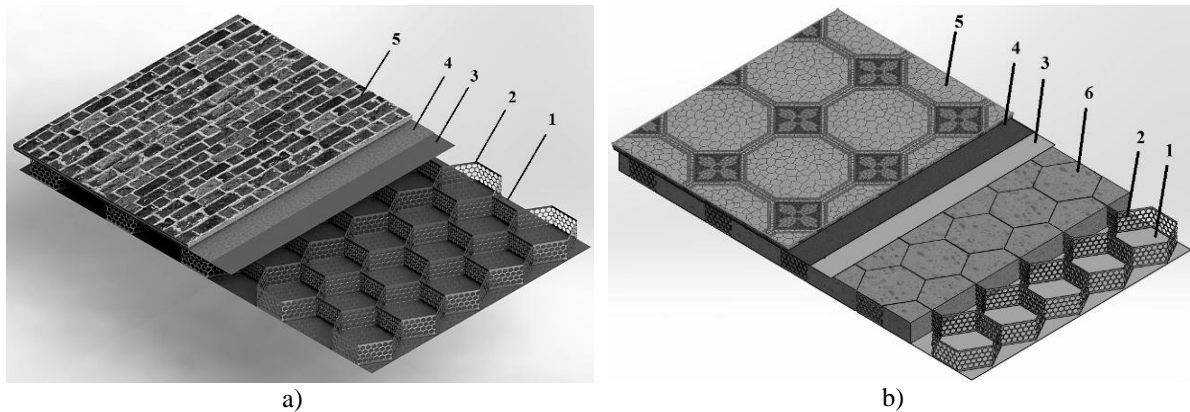


Figure 11. Example of sandwich panel based on perforated and profiled metal tape placed upright without an insulation layer (a) and with an insulation layer (b):

1 – lower metallic sheet; 2 – perforated and profiled metal tape; 3 – upper metallic sheet; 4 – layer of glue, 5 – facing (finishing) material; 6 – insulation material

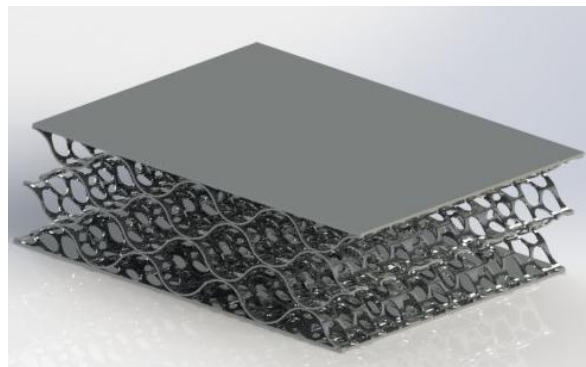


Figure 12. Example of a multilayer sandwich panel for absorption of mechanical energy based on perforated and profiled metal tape placed flatwise

CONCLUSION AND FOLLOW-UP STUDIES

Perforated metallic materials (tapes, plates, strips) have a big potential to be used in construction. It was shown that by profiling and welding - it is possible to produce different cellular structures, matching with filler material and decoration.

The computer simulation is a feasible way to predict the deformation of geometrically complex cellular structures, using perforated bands as well as

for form optimization in regard to the effective use of the material. The difference between results obtained by computer simulation and experimental work is in the range of 5%. Experiments (computer and mechanical testing) prove, that a cellular structure from perforated steel S235JRG2 strip have a high compressive strength, when the average carrying capacity is 2744 N.

One of the possible applications of perforated metallic materials in building construction, is

sandwich panels. Such sandwich panels after a detailed studies have good opportunities to be used as supporting or decorative structures. According to the core material and core location in the panel, the sandwich panels could be with high stiffness as well as with good absorption ability of mechanical energy. Filling of the cellular structure with insulating filler allows heat-insulating and sound-insulating properties of the sandwich panels to be improved.

Further studies will be linked to the development of effective methods for interconnection of metallic elements.

The obtained panel prototypes will be tested in 4 – point bending. The multilayer numerical model of sandwich panel will be created with aim to draw correlations, validate calculated results with experimental strain and deflection measurements, and optimise the design of sandwich panel.

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